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The Decoupling of Corrosion and Fatigue for Aircraft Service Life Management

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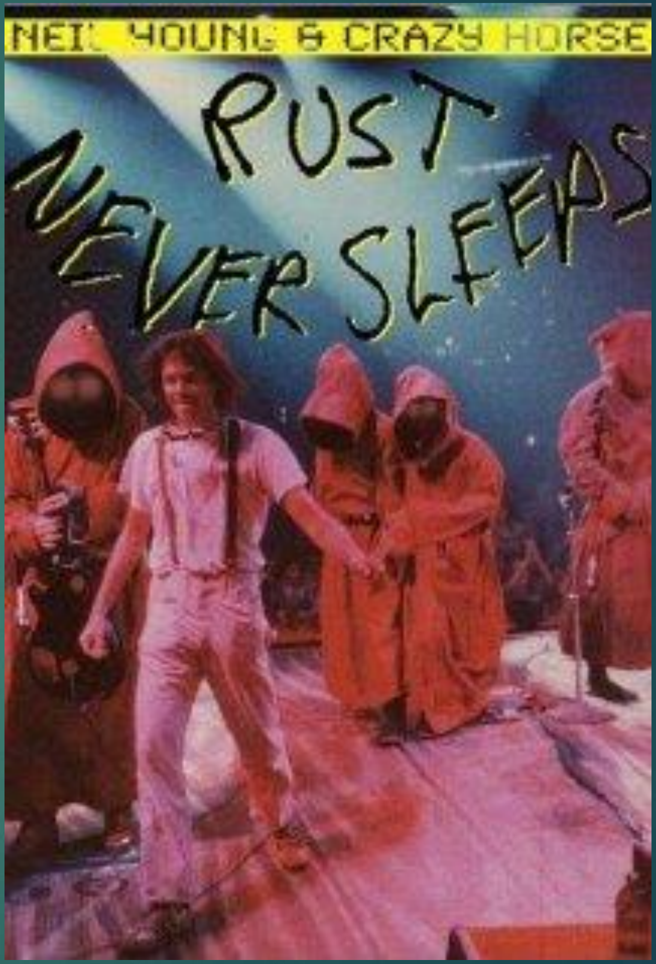
[CMDWC 2021]: STREAM "MATERIALS DEGRADATION IN DEFENCE AND CIVILIAN AIRCRAFT

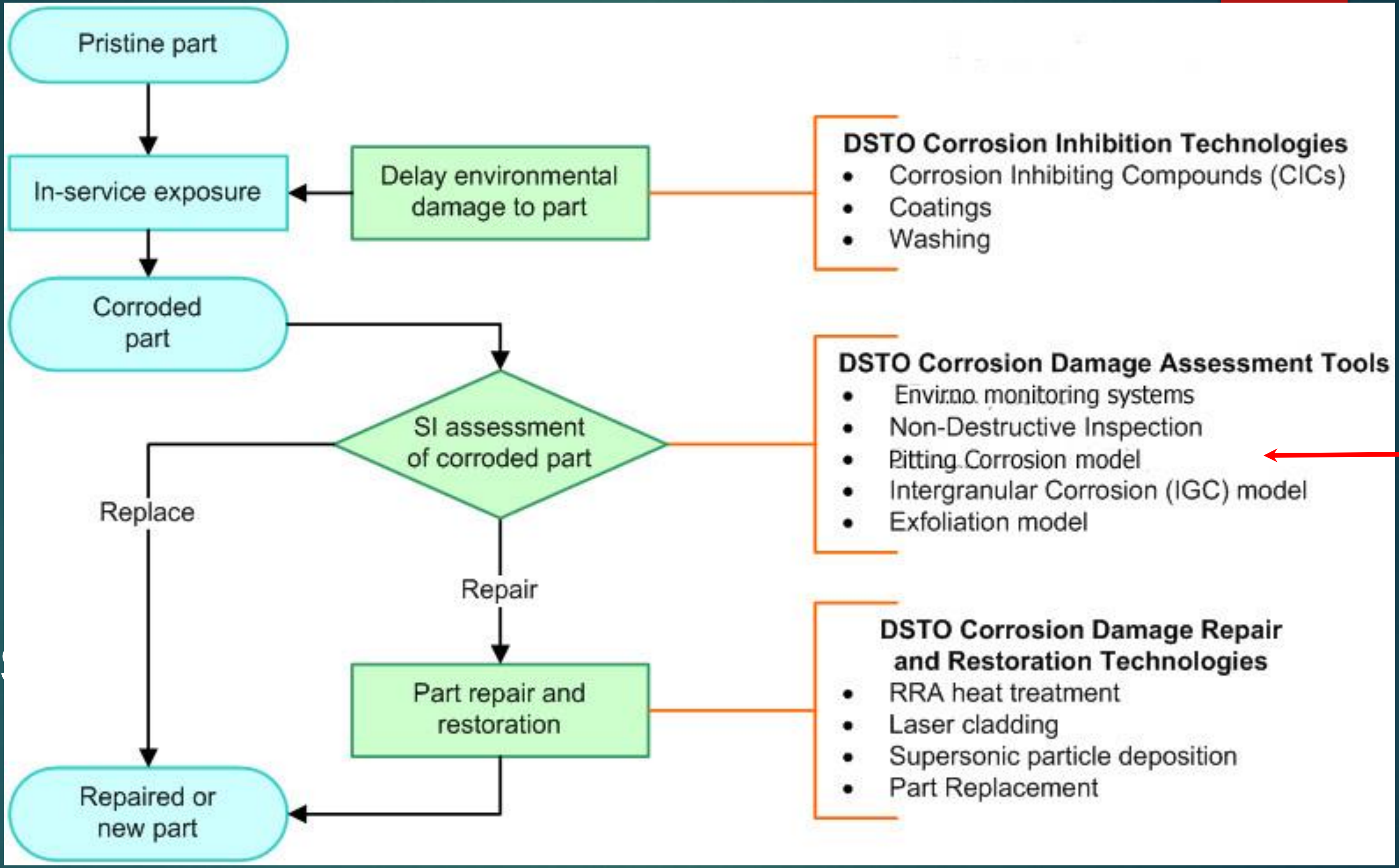
Rust Never Sleeps

Or does it?



Acknowledgements

DST Corrosion Tool Set



Crawford et al.

Overview

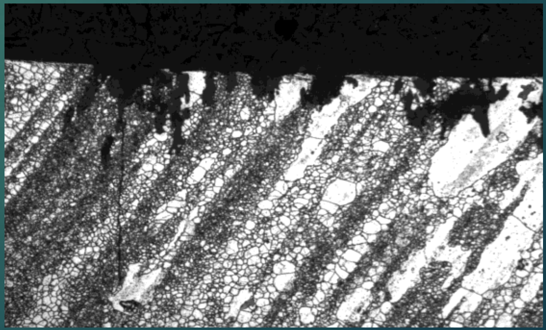
- Corrosion is a major cost driver for all Air Forces
- Corrosion is currently addressed by “find-and-fix”.
- This is largely due:
  - to the perception that corrosion presents an immediate safety threat; and
  - there are currently no mature tools to account for its impact on structural integrity.
- One major form of corrosion is pitting corrosion
- Corrosion pits will be considered here
- Does the environment influence crack growth?
- Are corrosion pits crack-like?

A view of corrosion pitting around a AA7050-T7451 lug.

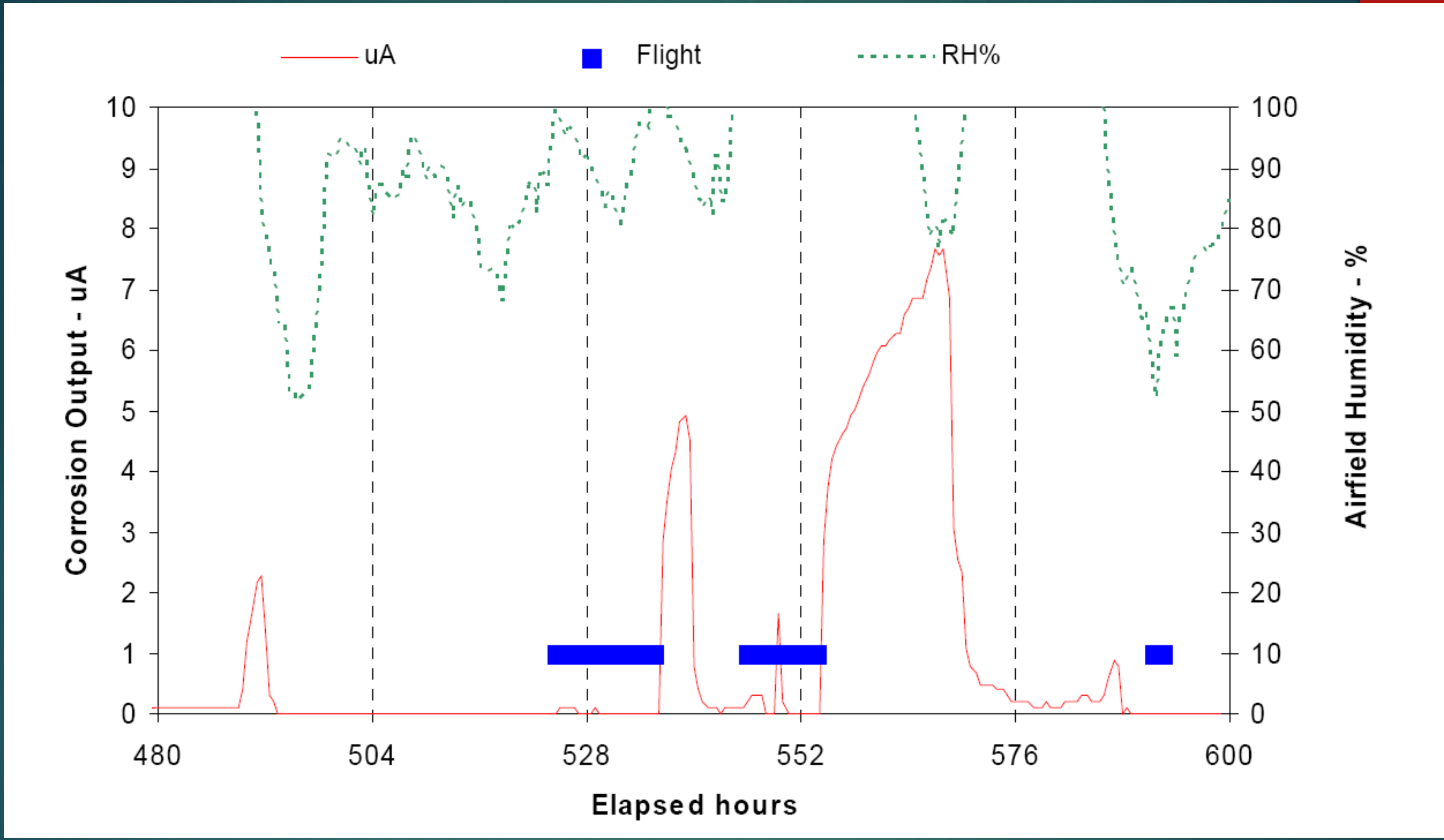
Eureka Moments

- Are corrosion pits like PITS? E.g. Hornet airframe covered in pits!
  - Critical Hornet structure etched prior to ion vapour deposited corrosion protection scheme.
- Corrosion occurs on the ground and fatigue crack growth occurs in-flight. Corrosion assisted fatigue is rare.
  - Thus the problem is **decoupled**! It's about growing pits in-flight, but nucleated on the ground.
- Not all pits lead to cracking

AA7050 specimen; fatigued then loaded to reveal cracks (dye penetrate)



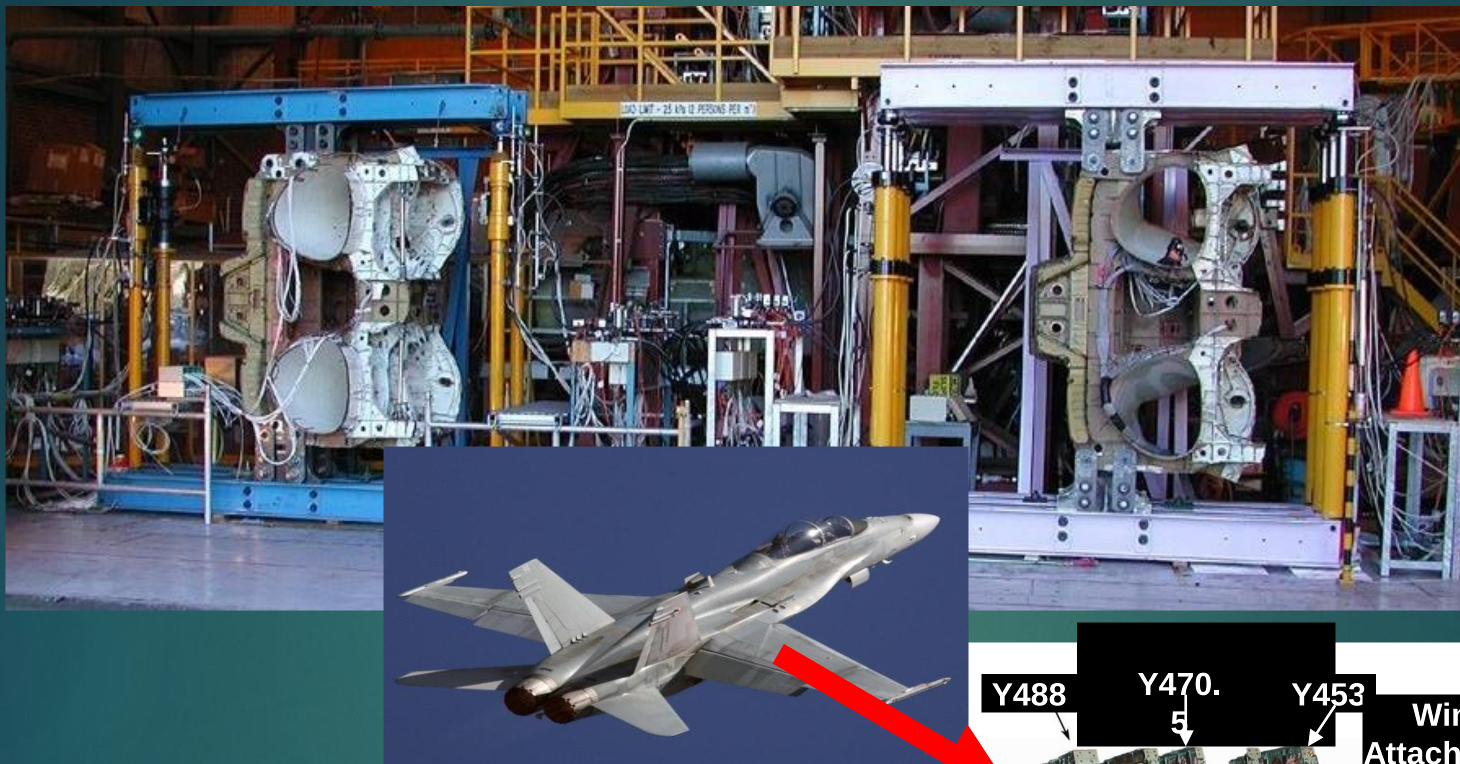
Where does aircraft corrosion occur?

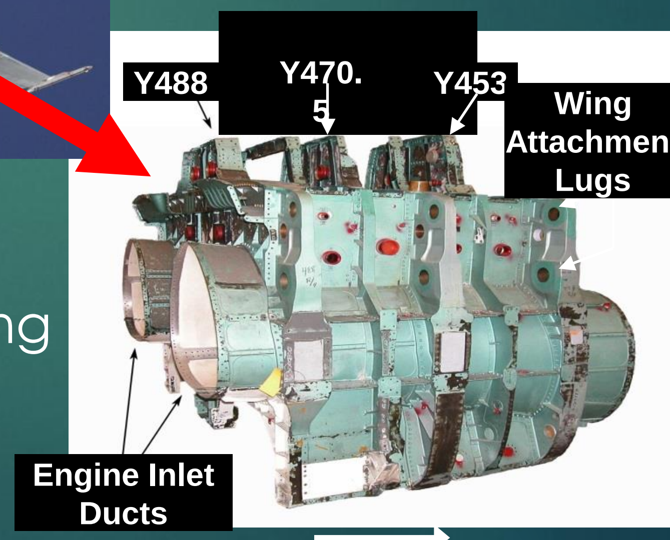


Typical output from the P-3C corrosion monitor, showing corrosion current (μA), periods of flight and airfield relative humidity (RH).

Trathen, PN. Corrosion Monitoring Systems on Military Aircraft.
Proceedings of the 18th International Corrosion Congress, Perth Australia November 2011

Flaw IdeNtification through the Application of Loads (FINAL)



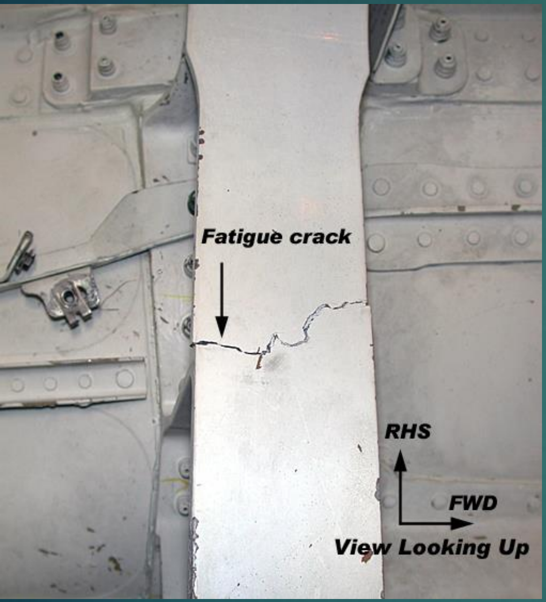


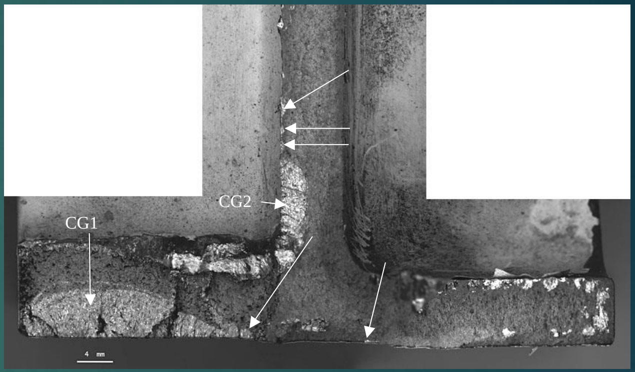
The testing of (mainly) ex-service wing attachment bulkheads

(1) Service crack from FINAL

- Testing of 16 centre barrels has generated data for over 1000 cracks.
- Cracking in one or two locations on the CB are relevant here:

AA7050-T7451

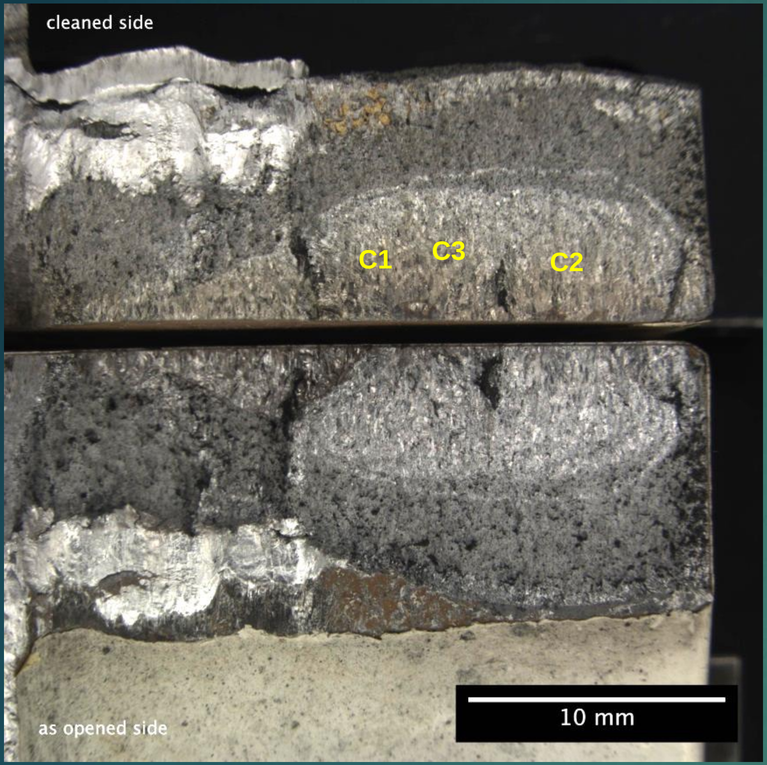




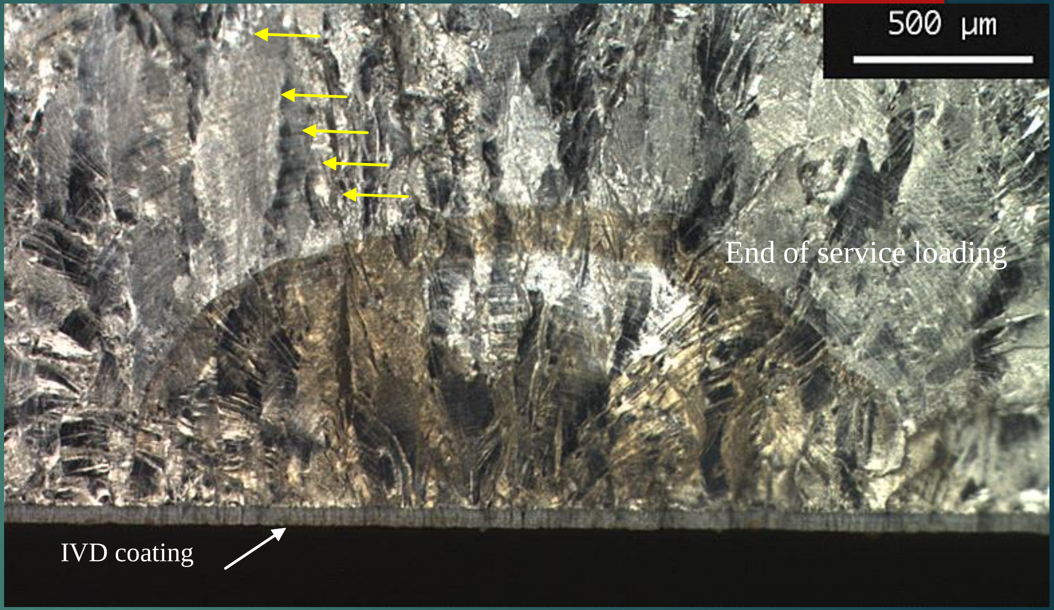
Case study CG1

(1) **View of the lower flange cracking in the Y470.5 bulkhead**.
This centre barrel had experienced approx 6000 hours in service prior to FINAL testing

Oxide Colouration



Comparison of the cleaned (nitric acid) side of the crack group one (CG1) fracture (top) and the "as broken" side (bottom)



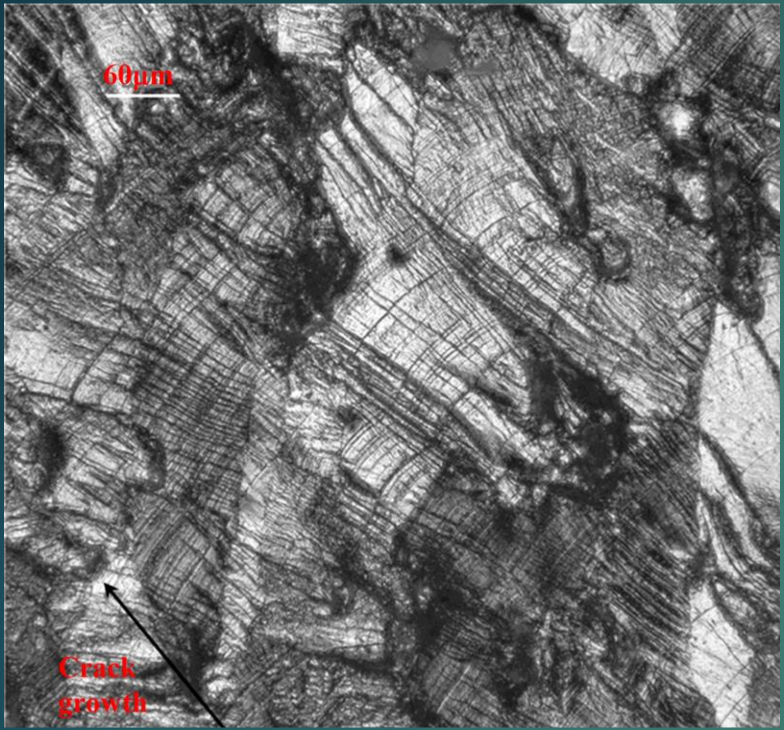
Optical view of the origin from the crack C1 in the Y470 bulkhead after cleaning.

Brown discoloured region was service crack growth. The end of service and the start of FINAL block loading and some progression marks, representative of FINAL block loading, have been highlighted with arrows

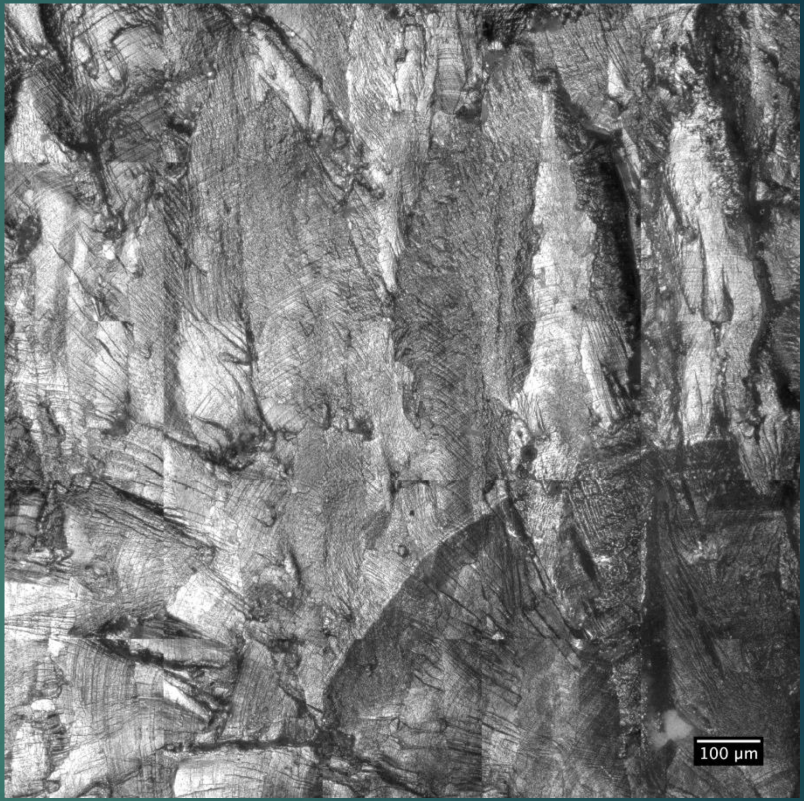
Oxide Colouration (2)

AA7050 specimen, pre-cracked and then exposed to mildly corrosive environment, shows similar discolouration.

Environmentally Assisted?

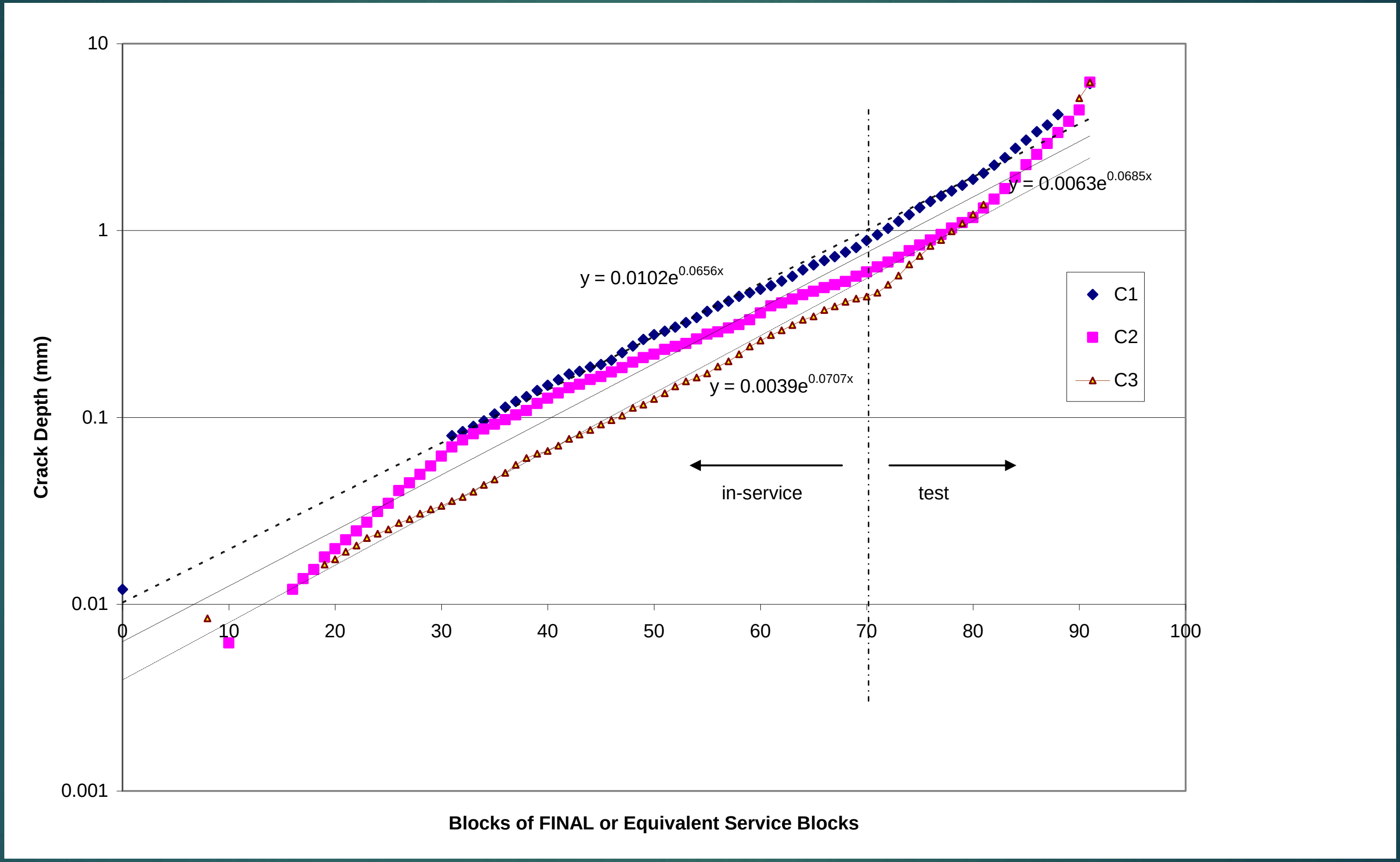


Optical view of part of the crack C1 in-service crack growth



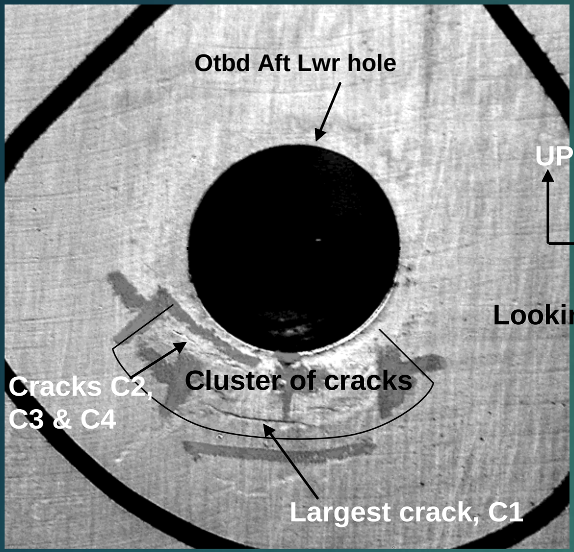
Optical view of the intersection region between the growth from in-service and from the FINAL loading for C1

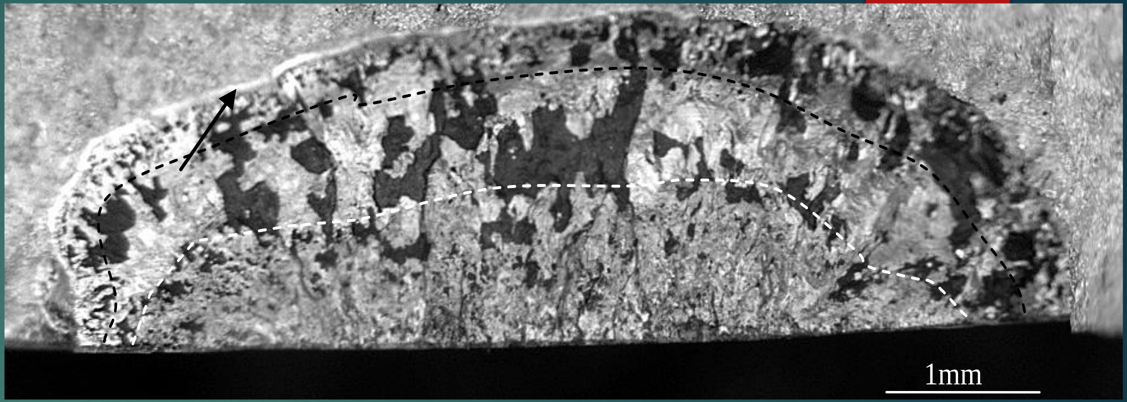
Environmentally Assisted Fatigue? (2) : No

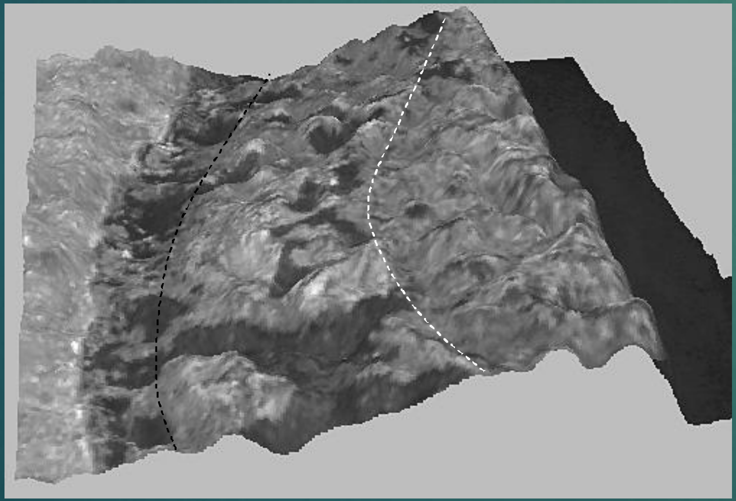


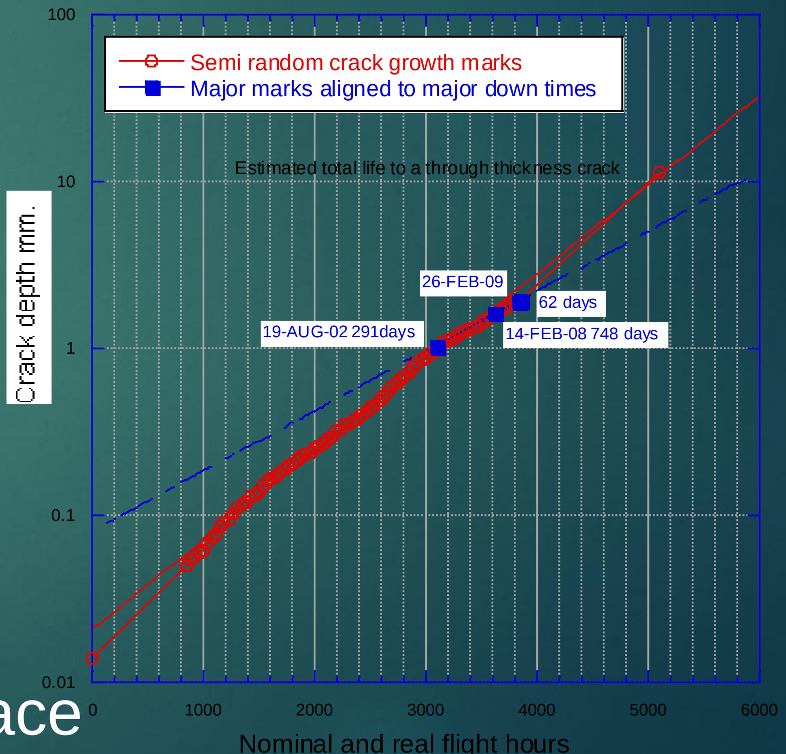
Crack growth for <u>three </u>major cracks on the Y470 bulkhead flange (“70 blocks” denotes start of FINAL testing)

(2) Effect of downtimes (service example)









topographical representation of surface

(3) The other examples

Case	Aircraft / Component	Material	Loading	Fatigue Initiation	Comments
1	F-28, BAC 1-11, 727-100 lap splices	2024-T3 Alclad	Service pressurisation cycles	Faying surfaces near or at rivet hole corners	No primary association between fatigue and corrosion
2	F/A-18 A-D vertical tail attachment stub frame	7050-T7452	Service (including significant aero-buffet)	Etch pits	Fracture surface showed corrosion areas corresponding to significant downtime periods. No evidence that FCG rate was affected by corrosion (see Figure 2).
3	F/A-18 A-D wing carry-through bulkhead	7050-T7451	Service and mini-FALSTAFF	Etch pit	In-service portion of crack showed exposure to corrosive environment. No evidence that FCG rate was affected by corrosion. (see Figure 7)
4	F/A-18 A wing carry-through bulkhead	7050-T7451	Mini-FALSTAFF	Corrosion pit	Pitting occurred before laboratory testing. No evidence that FCG rate was affected by corrosion (see Figure 3).
5	F/A-18 A-D MLG wheel hub	2014-T6	Service	Corrosion pit	In-service exposure: fatigue initiated from pitting. No evidence that FCG rate was affected by corrosion, despite harsh environment.
6	C130 Hercules FS 497 bow beam fitting	7075-T6	Service	Corrosion pits	In-service exposure produced pits, and also stress corrosion cracks perpendicular to fatigue cracking. Stress corrosion cracks apparently retarded fatigue crack growth (see Figure 4).
7	Iroquois main rotor yoke	4340 steel	Service	Corrosion pit	In-service exposure. Once fatigue cracking had started, it did not appear to have been influenced by corrosion (although corrosion had attacked the fatigue fracture surface (see Figure 5).
8	Macchi centre section lower spars (several)	4340 steel	Service/test	Corrosion pits	In-service exposure produced the initial pits and also FCG. Subsequent laboratory testing showed No evidence that the corrosive conditions had had any effect on the FCG rate.
9	F/A-18 A-D trailing edge flap hinge lug	7050-T73652	Service	Corrosion pit	In-service exposure. Early FCG appeared affected by corrosive conditions, as seen from brittle-looking progression markings. High tensile residual stresses and a water-entrapping crevice probably influenced this.
10	F-111 wing pivot fitting (several cases)	D6ac steel	Service	Corrosion pit	In-service exposure caused surface pitting that transitioned to FCG. A long downtime resulted in crack extension by stress corrosion cracking.

Unclassified – Approved for Public Release

The effect

- If the crack growth from pits in service are not significantly influenced by the environment, then how can we account for their potential impact on structural integrity?

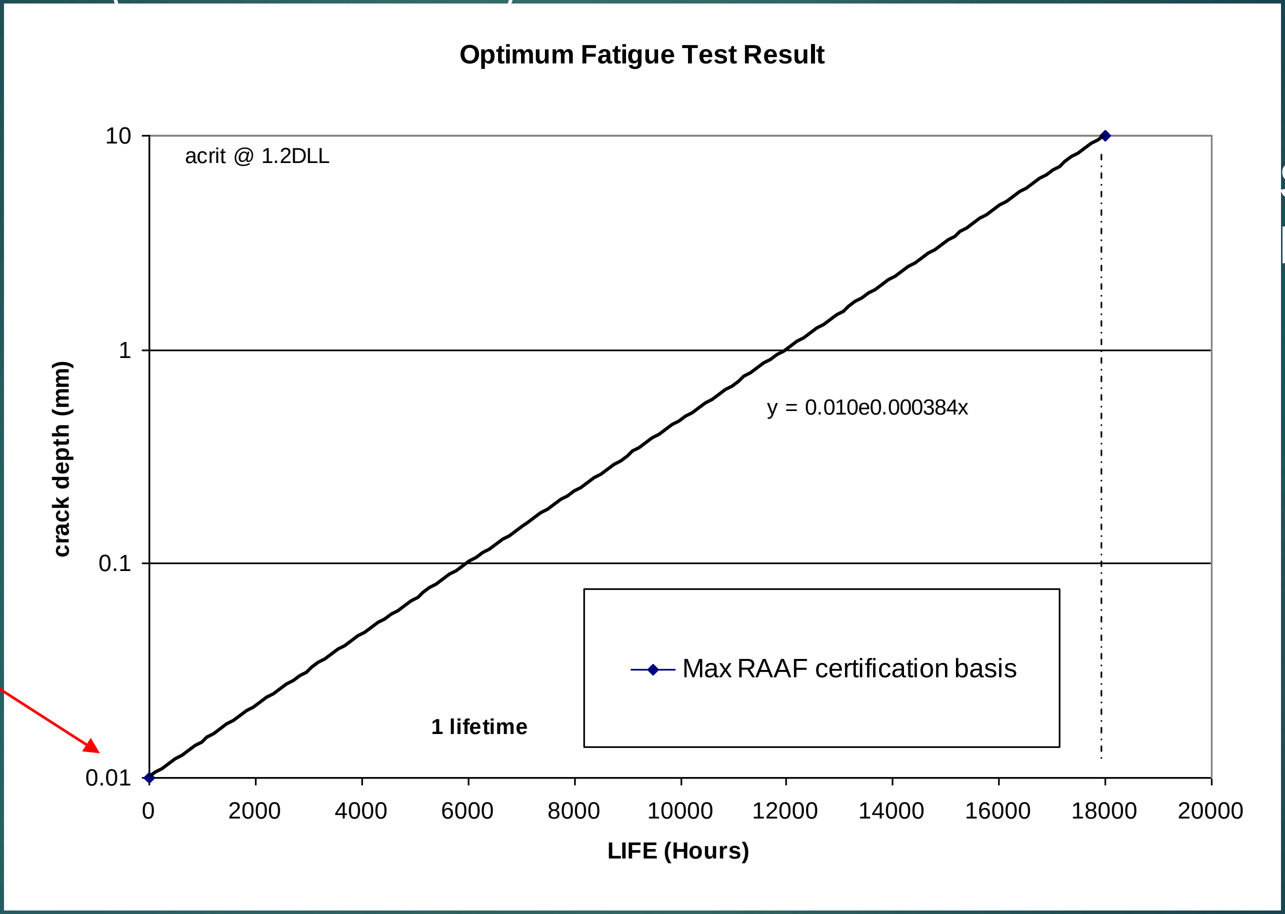
- ⇒ by considering the certification basis of the aircraft (ASIP).

- Example: The safe-life Hornet

St Louis 1984

Management of fatigue – through certification testing (etc)

- For an optimum design: a_{crit} just meets Residual Strength Criteria at end of FSFT (UK DEF STAN 970).



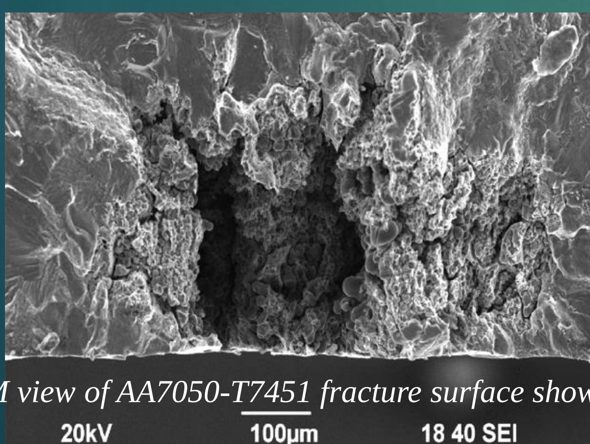
Scatter Factor = 3

Mean nucleation depth

This represents the fastest possible crack (Lead Crack Concept)

Corrosion Pit Nucleated Fatigue

- Currently cannot predict when corrosion will occur.
- However, pitting corrosion routinely found.
- Corrosion pits in AA can be deeper than pits from other sources (e.g. IVD) but are not very effective as cracks
- If corrosion occurs early in the life it may win the race against a non-corrosion initiated fatigue crack?
- From analyses and literature etc typical maximum pit depth in AA7050-T7451 is ≈ 200μm (CONSERVATIVE).

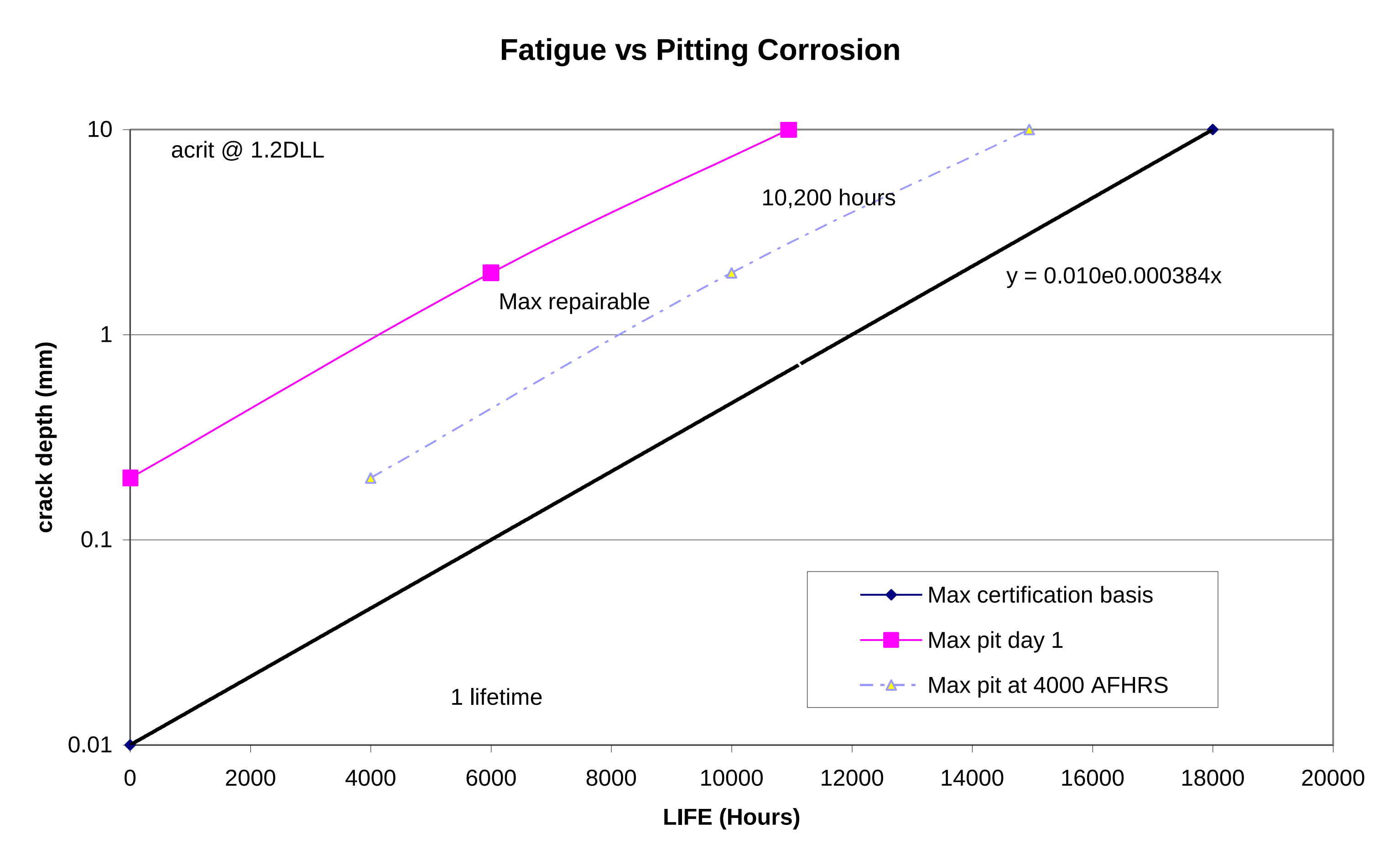


An SEM view of AA7050-T7451 fracture surface showing a corrosion pit produced in the laboratory: 3.5% NaCl solution exposure for 12 hours.

More Work needed to better define mean effective pit depth

Therefore:

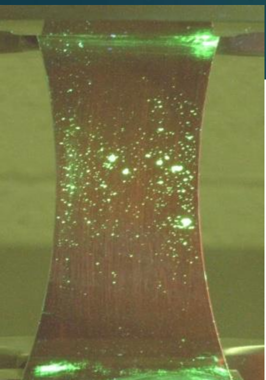
Corrosion Pit Initiated Fatigue (2)

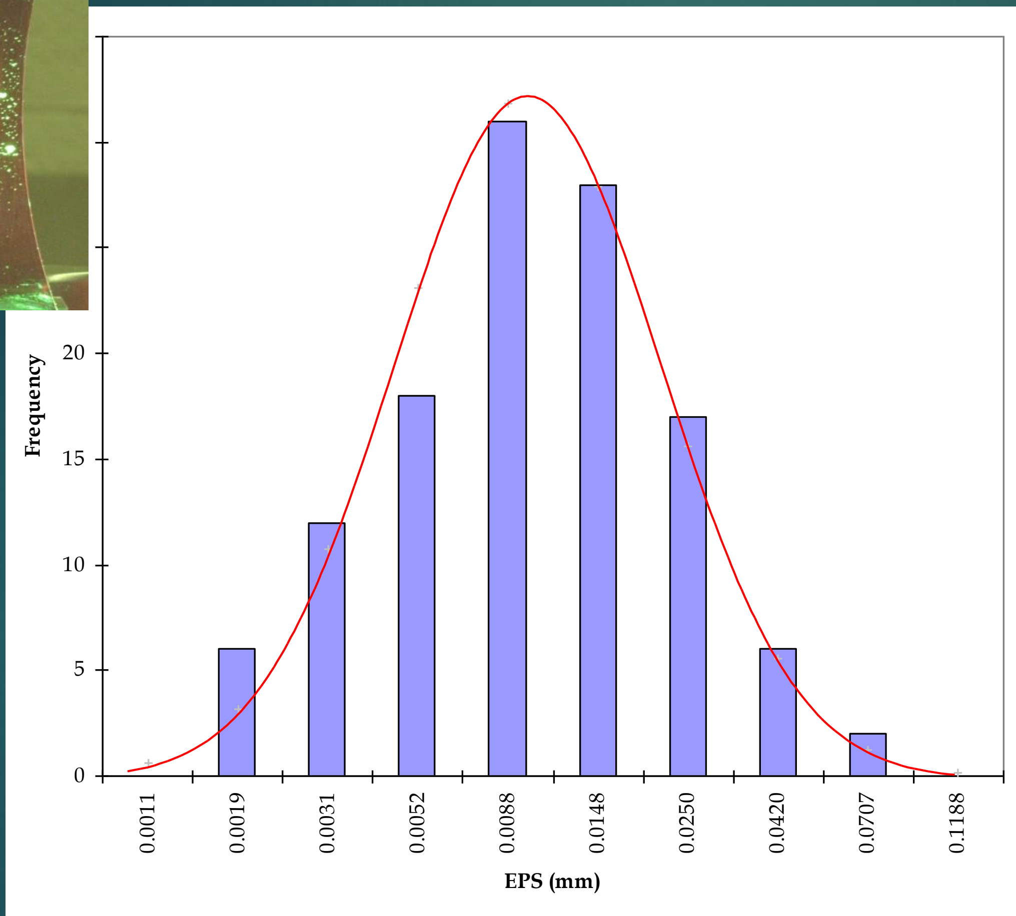


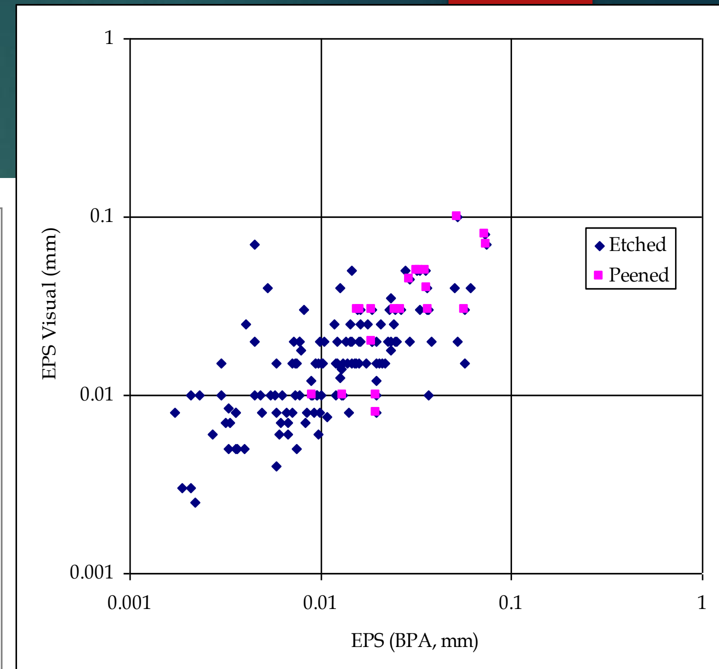
10,200 hours from nucleation to failure! Divide by scatter factor…. Significant safe period!

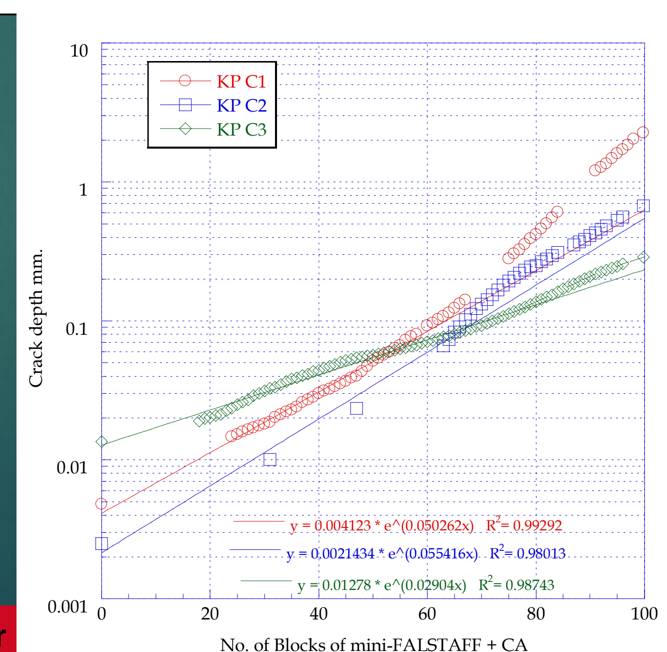
With proper procedures (see papers) can remain in service

Have EPS for etched pits etc, developing for corrosion pits in some materials (largely AA7050)









Log-normal distribution of the Equivalent Crack Pre-Size (EPS) of the etched coupon specimens – 120+ points

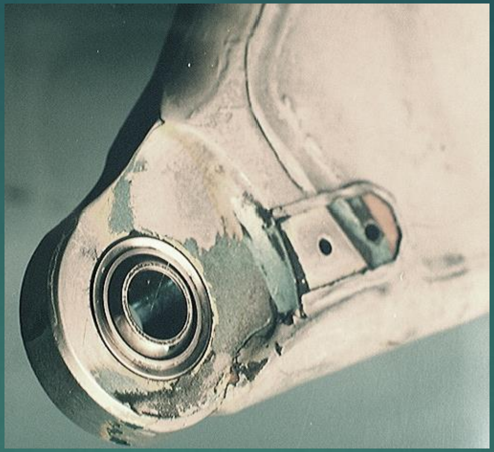
But things can go wrong….

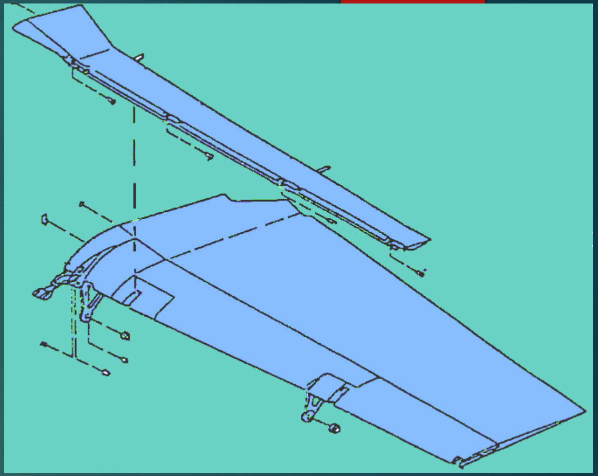
Hornet Flight Control

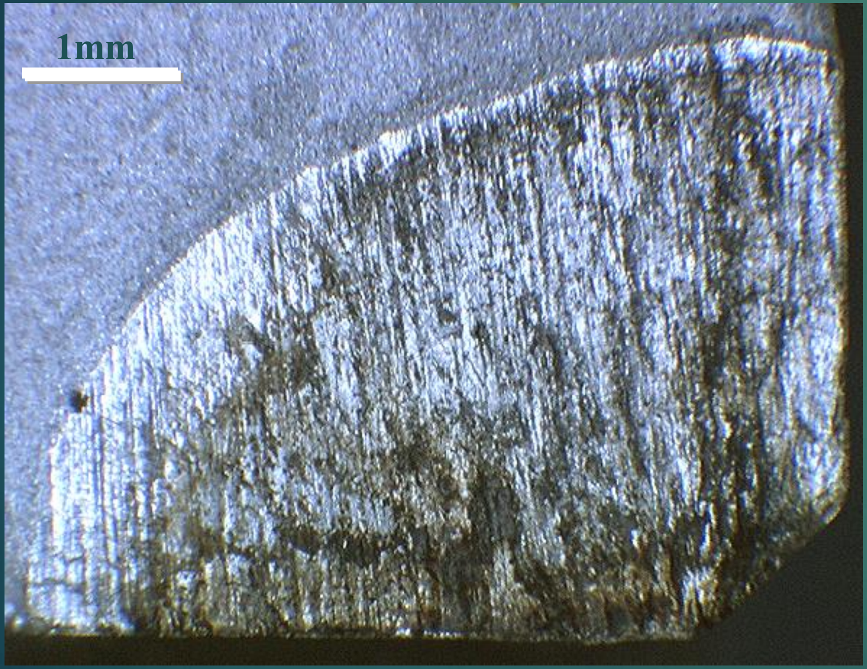
RH Trailing Edge Flap (TEF) departed during ACM

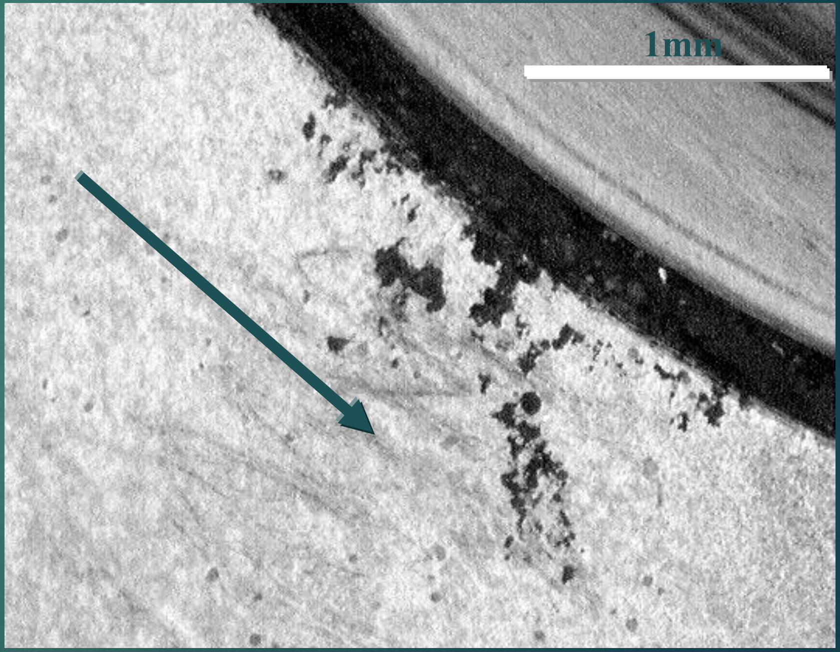
TEF destructive fleet aircraft inspections

AA7050-T73652 forging



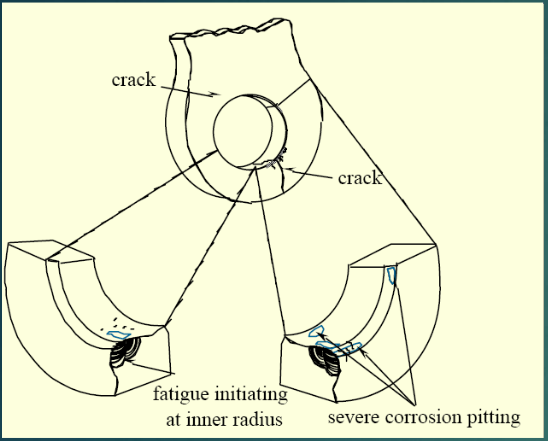


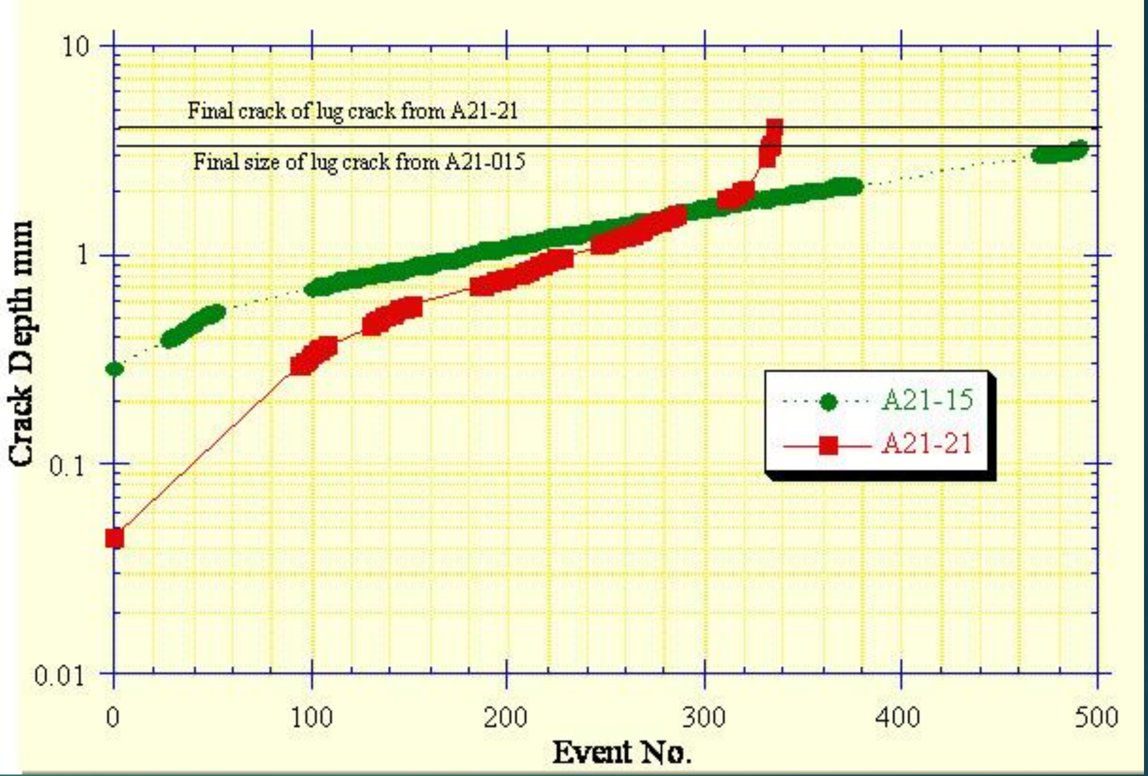




at approximately 1400-1500 flight hours

Crack Growth





Investigation:

- Monoball to lug assembly process led to significantly higher stresses
- Not fatigue tested
- Buffet not accounted for in design
- ASIP!

Conclusion

- Service exposure to ground-mildly-corrosive environment showed insignificant influence on in-sky crack growth.
- Not all corrosion pits effective at growing cracks
- Some corrosion pits not very effective cracks
- Using the lead crack concept and an understanding of pitting metric (i.e. effective depth) the affect of corrosion on structural integrity can be predicted.
- It appears that in **certified** airframe cracking from pitting corrosion can have a significant period of growth until it becomes non-repairable or critical.
- As long as ASIP requirements met!
- Thus pitting corrosion when found can be left until the next convenient planned maintenance.
- Thus saving $$ and increasing availability.

Bibliography

1. Barter S. and Molent L. Service fatigue cracking in an aircraft bulkhead exposed to a corrosive environment, Engineering Failure Analysis 34 (2013) 181–188.
2. Molent, L. Managing fatigue from corrosion pits – a proposal. Proc. AIAC15, Melb 25-28 Feb 2013.
3. Barter, S. and Molent L. Investigation of an in-service crack subjected to aerodynamic buffet and manoeuvre loads and exposed to a corrosive environment. Proc. 28th International Congress Of The Aeronautical Sciences, Brisbane 23-28 Sept 2012.
4. Barter SA, Molent L, Wanhill RJH. Typical fatigue-initiating discontinuities in metallic aircraft structures, J Fatigue 2012; 41:11-22.
5. Mills T, Sharp, PK and Loader, C. The incorporation of pitting corrosion damage into the F-111 fatigue life model. DSTO-RR-0237, Jun 2002.
6. Crawford BR, Loader C and Sharp PK. A proposed roadmap for transitioning DSTO's corrosion structural integrity research into Australian Defence Force service. DSTO-TR-2475, Oct 2010
7. Molent, L., Managing airframe fatigue from corrosion pits – a proposal, Engineering Fracture Mechanics 2015; 137: 12–25.
8. Loader C, Crawford BR, Sharp K and Molent L. A Proposal for the Management of Detected Pitting Corrosion for the F/A-18 Hornet, DSTO-TR-2976, Apr 14.
9. Molent L, Barter S and Wanhill RJH. The Decoupling of Corrosion and Fatigue for Aircraft Service Life Management. Proc ICAF 2015, 3-5 Jun 2015, Helsinki.

Special thanks

- For your attention.

and

- **RAAF, DST.**